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Management of Timber Road Bridges in Western Australia

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SUMMARY

This paper details the management system which has been adopted for the 1500 timber road bridges in Western Australia. The Main Roads Department of Western Australia has recently adopted a management strategy which will give it a wide spectrum of alternatives other than waiting until a bridge needs replacement. This has been prompted by both the funding and the practical problems which will be created because of the age and rates of deterioration of the timber bridges.

Management is based on a computerised information system fed by a systematic bridge inspection programme. This has produced many benefits including a greatly enhanced capacity for programming works on both a long and short horizon. It has also suggested a range of new design alternatives for old structures, and further developments are being made through a research programme.

1. INTRODUCTION

There is a 2000 year old bridge still in use in Spain which bears the inscription "I have built a bridge which will last forever". The inscription is signed by its Roman builder, and he is probably even more entitled to claim credit for the bridge's longevity if it was he who instituted the maintenance management plan which ensured its survival. This paper is concerned with bridge preservation - but not with just one bridge. It will consider the preservation of the whole group of 1500 timber road bridges spread over the south western region of Western Australia. The Roman bridge was made of stone which makes it inherently more durable than our timber bridges, but the process of decay in both cases is predominantly caused by water. For any particular bridge the actual mechanism of decay depends on the materials used and the local enviromental conditions, but in every case water plays a central role in the process. So the management problem is resolved largely into one of controlling the interaction of water and the structure for as long as it is to be kept in service.

The problem of rehabilitating and preserving Western Australia's timber bridges has two elements which make it a challenging one. The first is that there is a significant number of bridges, especially as they are spread over an area roughly the size of Great Britain. Their direct replacement value is approximately $200 million, and this excludes extra costs of roadworks often associated with replacement structures, and the community costs of extended periods of reduced service. The second is that timber suffers a much more rapid rate of decay than most other materials. Timber has been by far the most widely used bridge building material in this state since the 1830's, and it can be seen from Fig. 1 that relatively few bridges survive more than about sixty to eighty years. It can also be seen that about half of them are already 30 years old. This paper deals with the recent change of direction in the Main Roads Department of Western Australia wherein a conscious shift has been made from an approach of progressive replacement of timber bridges, to one of rehabilitation, preservation and upgrading to keep them in service for as long as it is economical to do so.

2. WESTERN AUSTRALIA'S TIMBER ROAD BRIDGES

The Main Roads Department have opted for a management strategy based on maintaining the existing infrastructure because it is clearly the most economic solution, but in a few special cases conservation of an historical asset also has had an influence. In the past several years technological developments on a number of fronts have produced a range of options for maintenance of individual structures which has resulted in significantly fewer replacements over the whole bridge population than previously. Fig. 2 shows this to be the case, for both Local Authority and Main Roads Department bridges. Although Fig. 2 is for all bridges, timber bridges form by far the greater proportion of replacements or specific maintenance expenditures.

2.1 Ownership of Bridges

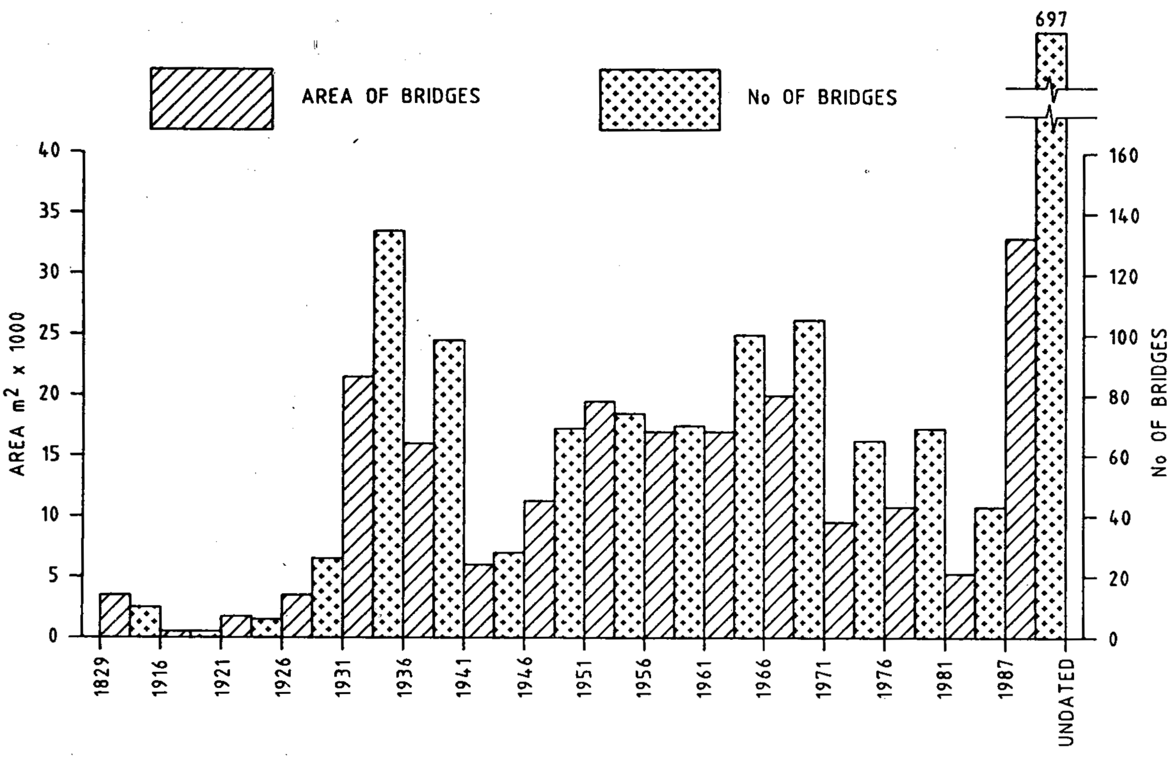
The Main Roads Department 'owns' (has direct responsibilty for, and totally funds) all the bridges which are associated with Freeways, Highways and Main Roads. In addition it has a statutory obligation to rate all bridges on public roads for safe load, although bridges on roads other than those mentioned above are 'owned' by Local Authorities, or in some cases the Department of Conservation and Land Management or the Water Authority. However the Main Roads Department provides much of the funding for Local Authority bridges. Thus because of its load rating responsibility and because they have a significant effect on the annual budget, the Main Roads Department now includes all of the Local Authority bridges directly into its management planning. The major new implication of this is that these bridges are now included in the systematic inspection programme without any direct charge to the Local Authorities. The reality is that many Local Authorities have limited engineering resources to direct towards assessing the condition of their bridges, especially as it is a fairly specialised area, and in many cases this has resulted in expenditures which could have been minimised with earlier action.

2.3 Variation in Timber Durability.

There is ample evidence from inspections carried out to date that the bridges built in the 1950's and 60's have used timber which deteriorates at a much more rapid rate than that used prewar. This is because in earlier times better timber was available, but supplies have been exhausted. In particular it is many years since wandoo has been generally available although many bridges built from this species are still in good condition even after 50 years. The other species mainly used is jarrah, but much of the jarrah used since the war has been regrowth timber which is much less durable than the original stock. The reduction in durability for the post war structures has in effect telescoped the maintenance management problem, or, especially if the replacement option is widely used, the funding problem.

2.4 Overall Management Approach.

Overall management in developing the programme of works is provided centrally from the Bridge Branch of the Department, although the separate operational Rural Divisions within the Department still carry out their traditional role of assessing local priorities with respect to new alignments, Local Authority requirements etc. However the deteriorating condition of the structures has become the primary determinant in prioritising actions, and this requires central management for logical relative rating of bridges. Central management also produces economies of scale in developing engineering expertise, utilising computer facilities,



TIMBER BRIDGE HISTOGRAM

TOTALS	TIMBER	NON TIMBER
NUMBER	1596	706
AREA m^2	193612	250231
REPLACEMENT VALUE \$ x 10^6	175	275

NOTE:
REPLACEMENT VALUE DOES NOT ALLOW FOR APPROACHES AND OTHER WORKS OR INCONVENIENCE TO PUBLIC DURING WORKS.

Figure 1 Age Distribution of Western Australia's Timber Road Bridges

acquiring and using inspection equipment, training of staff and in many other ways.

2.5 Strategies for Overall Management.

To simultaneously manage the whole population of bridges the following parallel strategies have been implemented:

2.5.1 Preliminary visual inspection

A preliminary or visual inspection has been made of all timber bridges which were either built prior to 1970, or which are of unknown age. This will be extended to the next 5 year period (1971 to 1975) in 1990 and each 5 years thereafter. A similar programme is being implemented for concrete and steel bridges. Adoption of a standard scoring system by trained inspectors has meant that a relative rating of all these bridges has therefore been developed.

2.5.2 Programme of actions for each bridge

From the visual inspection ratings priorities for actions on individual bridges have been derived. There are a range of planned actions including replacements, rehabilitations including improvement works, more simple rehabilitation works, localised structural repairs and commencement of preservation strategies.

2.5.3 Computer data base of planned actions

Planned actions have been entered into a computerised data base which acts as an information collating, processing and distribution system. Access to all of the information in this data base is available to everyone all the time. There is some scope for operational Divisional staff to modify the data base but essentially it is centrally managed through the Bridge Branch. The data base can now be used for forward planning, and for day to day management by everyone involved, from the operational staff who actually do the structural works to the designers, inspectors, foundation investigation staff etc.

2.5.4 Detailed Inspections

In conjunction with the other operations detailed inspections are made on the priority established from the visual inspections. These are necessary for several reasons:

- to confidently rate bridges for loading it is necessary to know the quantity of sound timber in members which may be partially deteriorated but still adequate.

- the extra information gained often influences the design, and may even indicate replacement.

- to enable major maintenance work to be planned in the most efficient manner.

- to ensure that all necessary repairs are carried out at the time of any major

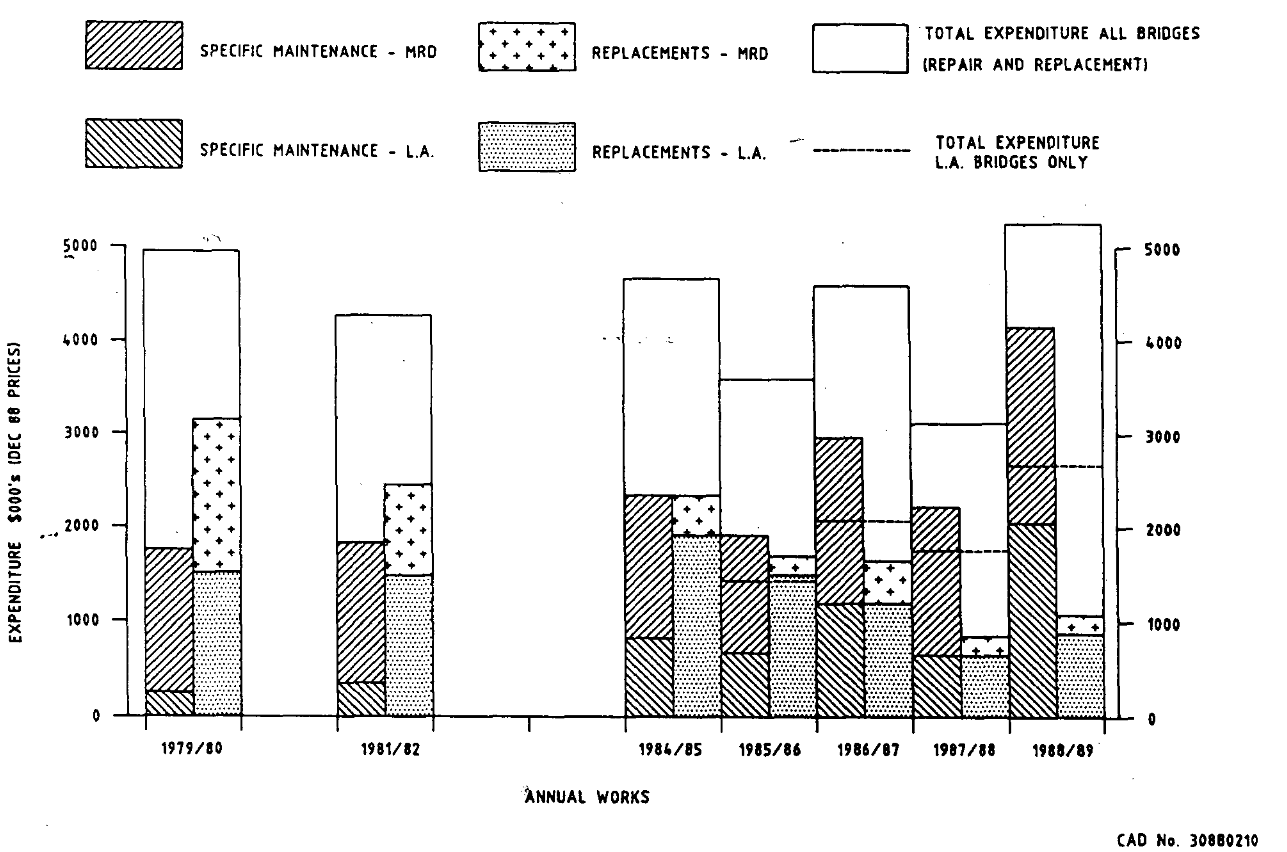


Figure 2 Record of Past Expenditure for Bridge Maintenance and Replacement

maintenance operation, and equally to objectively assess whether a repair is actually necessary.

- to eventually provide a time series of data which will show the effectiveness of preservation strategies.

Documented data including reports and photographs from both the visual and detailed inspections are kept in a special bridge maintenance library.

2.5.5 Engineering design

For each individual maintenance job an engineering design is carried out. This could range from the adoption of a standard solution through to a completely original one depending on the situation.

2.5.6 Research and development

There is an ongoing research and development programme ranging from literature searches through to experiment based investigative research projects.

These individual strategies will now be separately elaborated on in the rest of the paper.

3. COMPUTER MANAGEMENT SYSTEM

3.1 Elements of the System

The Main Roads Department of Western Australia has developed a computer based management approach to be used in conjunction with its maintenance inspection library for its timber (and other) bridges. This system has two branches. The first is a Bridge Inventory which contains all the essential features and elements of the bridges such as number and length of spans, width, number and size of longitudinal members (stringers), number of piles per pier etc. This was originally developed to rate timber bridges for heavy load permits. It is a 'hard' data base. It must be accurate and kept up to date, with limited and very controlled access to maintain it. It is also linked to the Department's road data base, so that each bridge can be precisely located, and its local road characteristics (traffic data, seal width etc) are readily available. The second branch is called the Bridge Management System (BMS). This is a 'softer' data base with several levels of increasingly broad access. There is adequate opportunity for every appropriate person to modify the data base, and the access and communication implied is set up so that each managerial hierachy will be aware when the data base has been modified in a way which affects it. The BMS is therefore an information dissemination and development system available at enquiry level to everyone and at development level to appropriate managerial hierachies, with an appropriate communications obligation.

3.2 Using the Bridge Management System to Plan Actions.

Based initially on the visual inspection information a course of action is decided for each bridge which is keyed into the BMS. This could range from doing nothing except scheduling a reinspection through to replacement of the structure. For each of these planned actions a date for execution and an urgency rating will be set. The precision of the date will depend on how soon the action is required to be carried out, and these dates can be programmed to within a month. The date is also affected by the urgency of the action. For example a visual inspection may be programmed to occur in a particular month of the next year but have a low urgency rating, meaning it can readily be rescheduled to accommodate practical considerations. If rescheduled to a later date it might acquire a higher urgency. Conversely a rehabilitation of a rotting timber deck might be scheduled within two years, because several more winters' rain will significantly deteriorate it and may result in much more expensive repairs, or even affect the bridge's load rating. Such an item would receive a high urgency rating. Once prioritised by the action dates, which are essentially based on a structural condition rating, the schedule is further rationalised based on practical and other considerations (such as inadequate width or strength) but always also considering the urgency ratings. The latter requirements tend to come from the operational Divisions. There is scope for input of explanatory comments for each item, the first two lines of which are printed out in most reports, even on screen enquiries.

3.3 Specific and Routine Items

More will be said in the next section of the paper about the various maintenance design alternatives, but planned actions are divided into two distinct groups which assist with the managerially hierachical access. The groups are characterised as 'specific items' and 'routine items'. Specific items are those which will either individually, or grouped with other specific items, form a particular Departmental Works Programme Proposal. Each of these Works Programme Proposals must be individually approved for the Department's annual expenditure programme of the year in which the work is to be carried out. Routine items are any others at all. Specific items are generally significant structural works, with a reasonably substantial individual cost, whereas routine items can range from 'line functions' such as drawings, survey, foundations investigation etc for which costs are kept in other management systems, to routine bridge maintenance actions such as vegetation control, repair of damaged handrails, vandal repairs etc, which are budgeted for from general routine maintenance cost items rather than as specific items. From this it is evident that expenditure approval authority is the basis for deciding the hierarchy of access, though input in deciding what is put up for approval must be maintained for all appropriate personnel.

3.3 Resource and Function Management

Fig. 3 shows examples of the reports which can range from the local functional area

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  REPORT: BIPRPT84                          M A I N  R O A D S  D E P A R T M E N T                        PAGE:       1
 PROGRAM: BIPRPT84                              W E S T E R N  A U S T R A L I A                           DATE: 20/12/88
  SYSTEM: BRIDGE MAINTENANCE                                                                               TIME: 15:31:43
                                      PLANNED SPECIFIC MAINTENANCE EXPENSE REPORT
 SELECTION CRITERA: DIV:7(METROPOLITAN)

                                                           NOTE: INFLATION FACTORS APPLIED TO GIVE CURRENT DOLLARS
                        ROAD CATEGORY: HIGHWAYS AND MAIN ROADS
-------------------------------------------------------------------------------------------------------------------------------
|BRDGE| BRIDGE NAME                  |DIV|LG|ROAD | SLKM | TYP |SPN| AADT|BUILT|LNGTH|WDTH| DOLLARS IN THOUSANDS WITHIN FINANCIAL YEAR|
| NUM |                              |   |  |     |      |     |   |     |     | (M) |(M) | | 1989 | 1990 | 1991 | 1992 | 1993 | 1994+|
-------------------------------------------------------------------------------------------------------------------------------
                                                                                          |      |      |      |      |      |      |
-------------------------------------------------------------------------------------------------------------------------------
  0002  CANNING RIVER                 7 104 H001   16.95 TIMB 13          1936  78.57  9.22 |      |    30|      |      |      |      |
WK DESC($,000): 1:CONCRETE OVERLAY(    30)BMRE                                              |      |      |      |      |      |      |
COMMENTS:1 : REPAIR JOINTS AND TREAT TIMBER                                                 |      |      |      |      |      |      |
        REPLACEMENT MAY BE JUSTIFIED BY DETAILED INSPECTION                                 |      |      |      |      |      |      |
-------------------------------------------------------------------------------------------------------------------------------
  0127  SERPENTINE RIVER              7 108 M002   24.56 TIMB  7          1935  42.70 10.36 |      |      |      |      |      |      |
WK DESC($,000): 1:REPL W/NEW BRIDGE(    66)BMRE                                             |      |      |      |      |      |      |
COMMENTS:1 : ON 87/88 PROGRAMME FOR RC OVERLAY                                              |      |      |      |      |      |      |
-------------------------------------------------------------------------------------------------------------------------------
  0368  WOORLOO BROOK                 7 106 M026   30.63 TIMB  2          1946  12.78  8.92 |    80|      |      |      |      |      |
WK DESC($,000): 1:STRUCTURAL REPAIR(    80)BMRE                                             |      |      |      |      |      |      |
COMMENTS:1 : SUPERSTRUCTURE ONLY TO BE REPLACED (PSC PLANKS)                                |      |      |      |      |      |      |
-------------------------------------------------------------------------------------------------------------------------------
                        ...ONG BR     7 101 M044   19.51 TIMB  6          1939  36.60  8.83 |     9|      |      |      |      |      |
                               4)BMRE      2:CONCRETE OVERLAY(     4)PJW                    |      |      |      |      |      |      |
                                                         ...ENING YR 1 - 8/86               |      |      |      |      |      |      |
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        FORCES APPLIED ...
-------------------------------------------------------------------------------------------------------------------------------
  0932  CAUSEWAY (VICTORIA PARK E     7 124 H001    0.61 ...
WK DESC($,000): 1:STRUCTURAL REPAIR(    30)BMRE
COMMENTS:1 : CONCRETE OVERLAY OF FOOTWAY (INCLUDES BRG 914)
-------------------------------------------------------------------------------------------------------------------------------
  0953  NARROWS BRIDGE - SWAN RIV     7 126 H015    0.19 PRES  5          1959 335.28 26.89 |    70|   600|      |      |      |      |
WK DESC($,000): 1:STRUCTURAL REPAIR(    70)BMRE     2:STRUCTURAL REPAIR(  600)BMRE          |      |      |      |      |      |      |
COMMENTS:1 : UPGRADE EXPANSION JOINTS                                                       |      |      |      |      |      |      |
         2 : STRENGTHENING OF SUPERSTRUCTURE                                                |      |      |      |      |      |      |
-------------------------------------------------------------------------------------------------------------------------------
  9009  DEAN STREET FOOTBRIDGE        7 115 H014    8.69 STEE  5          1972  98.00  2.13 |      |    20|      |      |      |      |
WK DESC($,000): 1:STRUCTURAL REPAIR(    20)BMRE                                             |      |      |      |      |      |      |
COMMENTS:1 : REPAINTING                                                                     |      |      |      |      |      |      |
-------------------------------------------------------------------------------------------------------------------------------
  9033  COTTESLOE PRIMARY SCHOOL      7 123 H014   11.15 STEE 12          1975 125.21  2.18 |      |      |      |      |      |      |
WK DESC($,000): 1:STRUCTURAL REPAIR(    30)BMRE                                             |      |      |      |      |      |      |
COMMENTS:1 : GENERAL REPAIRS                                                                |      |      |      |      |      |      |
------------------------------------------------------------------------------------------- | 1989 | 1990 | 1991 | 1992 | 1993 | 1994+|
HIGHWAYS AND MAIN ROADS TOTALS FOR ALL...20 BRIDGES LISTED                                  |   335|   680|    64|      |      |      |
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    REPORT: BIPRPT82                              M A I N  R O A D S  D E P A R T M E N T                  PAGE:       31
   PROGRAM: BIPRPT82                                  W E S T E R N  A U S T R A L I A                     DATE: 06/12/88
    SYSTEM: BRIDGE MAINTENANCE                                                                             TIME: 14:52:41
                                    PLANNED ROUTINE  REPORT OF ITEMS WITHIN BRIDGE
  -----------------------------------------------------------------------------------------------------------------------
  SELECTION CRITERA: DIV:2(BUNBURY)                                                               ORDER SHOWN: BRIDGE

    BR   DIV  LG ROAD  SLKM    TYPE          SPANS  JOB    --- WORK ALLOCATED ---    AUTH ------ PRIORITY -----------  DATE       EST
    NO.   NO  NO  NO                                NO.     ITEM NO.  DESCRIPTION     BY RTNG INITIAL CURRENT  CHGD-BY  STARTED   $COST
  -----------------------------------------------------------------------------------------------------------------------
           2 206 0034    1.29  1(TIMBER)      1             703 DETAILED BRIDGE INSP  PJW   5  01/1993 01/1991 BMDE                1500
  --------- PWD BRIDGE, IN PADDOCK

   3509
           2 206 0070    0.24  1(TIMBER)      2             703 DETAILED BRIDGE INSP  PJW   5  02/1992 02/1992                     1000
  --------- PWD BRIDGE,  LONG SPANS

   3510  PRESTON RIVER
           2 206 0072    0.48  1(TIMBER)      6             721 SIGNS & LIGHTS        PJW   1  07/1988 07/1988                     1000
  --------- SINGLE LANE SIGN REQ'D - 5/86
                                                            703 DETAILED BRIDGE INSP  PJW   4  05/1989 05/1989 BMDE                5250
  --------- REPLACE YR 5+ 72 - 22-5-86

   3511
           2 206 0073    0.80  1(TIMBER)      2             656 ERADICT TERMITE/FUNG  PJW   3  07/1988 07/1988                     1000
                                                            721 SIGNS & LIGHTS        PJW   3  07/1988 07/1988                     1000
  --------- WIDTH MARKERS YR 1 - 11/86
                                                            703 DETAILED BRIDGE INSP  PJW   5  11/1992 11/1992 BMDE                2250
  --------- PWD BRIDGE??

  03512  REPLACED
           2 206 0074    0.80  1(TIMBER)      1             736 DRAWINGS              PJW   1  07/1988 07/1988                        1
  --------- AMEND INVENTORY AS NEW BRIDGE HAS BEEN BUILT
                                                            703 DETAILED BRIDGE INSP  PJW   5  12/1991 12/1991                     1000
  --------- PWD PLANK BRIDGE

  03513
           2 206 0077    0.40  1(TIMBER)      1             736 DRAWINGS              PJW   1  07/1988 07/1988                        1
  --------- AMEND INVENTORY AS NEW BRIDGE HAS BEEN BUILT
                                                            703 DETAILED BRIDGE INSP  PJW   5  01/1993 01/1993                     1000
  --------- BRIDGE 3513A - PWD PLANK BRIDGE

   3514  PRESTON RIVER
           2 206 0078    0.48  1(TIMBER)      5             703 DETAILED BRIDGE INSP  PJW   5  02/1992 02/1992                     1000
  --------- GRAVEL ROAD SURFACE, ON SEVERE 'S-BEND'
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Figure 3 Reports from the Bridge Management System

manager's short term horizon for routine items, through to the long term budgeting of specific items which can also indicate long term staffing, skills and other resource requirements. Each local function manager can immediately see what the other managers linked to his process are planning. For example the drawing office manager can see when he has to have his drawings ready to meet the operational Divisions' planning for execution of the current annual Departmental Works Programme, and the manager of the bridge inspections or the foundations investigation can see when his work will be required for the design and drawings. Horizontal verbal communication across these linked functional areas is also encouraged, so that any problems can be accomodated by reprogramming with minimum fuss, and everyone has an up to date picture of his obligations on the BMS.

The other side of the BMS is that it can give a picture of the progress of work and the costs. Particularly for specific items, costs adjusted for inflation to current dollars are kept which enable more accurate estimating to be carried out for future budgeting. The system also ensures that the all important 'as constructed' information has been received, so that the 'hard' data base in the Bridge Inventory can be kept accurate and up to date. Costs are also kept where required for routine items but this is left to the discretion of local functional area managers.

4. BRIDGE MAINTENANCE DESIGN OPTIONS

Until about 1985 aging timber bridges in Western Australia were often replaced, largely at the instigation of the operational Divisions who control them, although an important alternative had begun to be developed in the Bridge Branch in the early 1970's. This alternative has become known as the reinforced concrete overlay (rco). A typical cross-section of a modern rco is shown in Fig. 4. These were used mainly in the Metropolitan region which was immediately under the construction jurisdiction of the Bridge Branch, and also Northam Division, but they began to appear elsewhere in the 1980's as Bridge Branch personnel were transferred into some of the other Divisions. Probably as recently as 1985 the rco was still considered a relatively short term solution, and it was expected to increase the 'life' of the structure by about fifteen years. This attitude changed drastically from about that time, for two reasons. Firstly, although certain design changes were indicated, the rco's were giving better longevity than had been initially assumed. Secondly, the recently commenced systematic preliminary bridge inspections began to provide an overall picture of data. This indicated that longer term lower cost solutions had to be sought, particularly for Local Authority bridges, which tended to be either undermaintained until replacements were unavoidable, or in some cases replaced unnecessarily. Various rehabilitation options will now be discussed but the first option considered will be the rco, because as this design evolved its potential to provide enormous cost savings combined with a greatly improved service to the public generated the present management approach and suggested other design improvements.

4.1 The Reinforced Concrete Overlay

It has become apparent over the years that rco's preserve and enhance bridges in a number of complementary ways. It is obvious that they are structurally stronger than the gravel pavements they replace, although they do not increase dead load. This means that they themselves do not break down under repeated heavy traffic loads, and they also distribute the load more evenly and with less vibration to the rest of the timber structure, which ensures that bolted and spiked connections last much better, and the timbers are less stressed. Where rco's have been placed over old planks which used to loosen rapidly after being respiked over many years, all of these old timber components have been saved, and given no further problems.

The other and almost more important benefit they have provided is that they have acted as a roof, shedding water away from the the rest of the timber structure. In the Introduction it was stated that the management problem was one of 'controlling the interaction of water and the structure for as long as it is to be kept in service'. If the bridge deck is considered as a piece of road, road managers would not tolerate the roughness and constant patching required as the gravel fines were lost after about fifteen to twenty years. In the past this has led to replacement of the pavement, but its longevity was reduced as the planks loosened easily after having to be respiked because the spikes had rusted and their holes rotted. All of these spike holes, including those in the longitudinal member onto which the planks are fastened (stringers) become repositories for water which causes rot. As the gravel pavement disintegrates it becomes almost like a large sponge storing water and creating perfect conditions for fungal decay (rot). Instead of being a localised problem which makes it difficult to keep spikes in place, the rot becomes more widespread and actually begins to reduce structural strength. Once the rot has started, termites attack, and they accelerate the process by spreading moisture, fungal spore and clearing away the initially rotting timber front.

In the past at this stage all the deck planks were replaced, and a new gravel pavement installed. However unless all the stringers were replaced (a complete new superstructure) even this was relatively short-lived. The modern concrete overlay overcomes all these problems, and particularly as the timber prices have risen, it has become actually cheaper than the alternatives. A further benefit is that as the timber protected by the overlay dries out, not only does the rot stop, but also the termites disappear which appears to confirm the theory that termites are associated with and preceded by moisture and rot. This solves another problem, because it is preferable to avoid having to

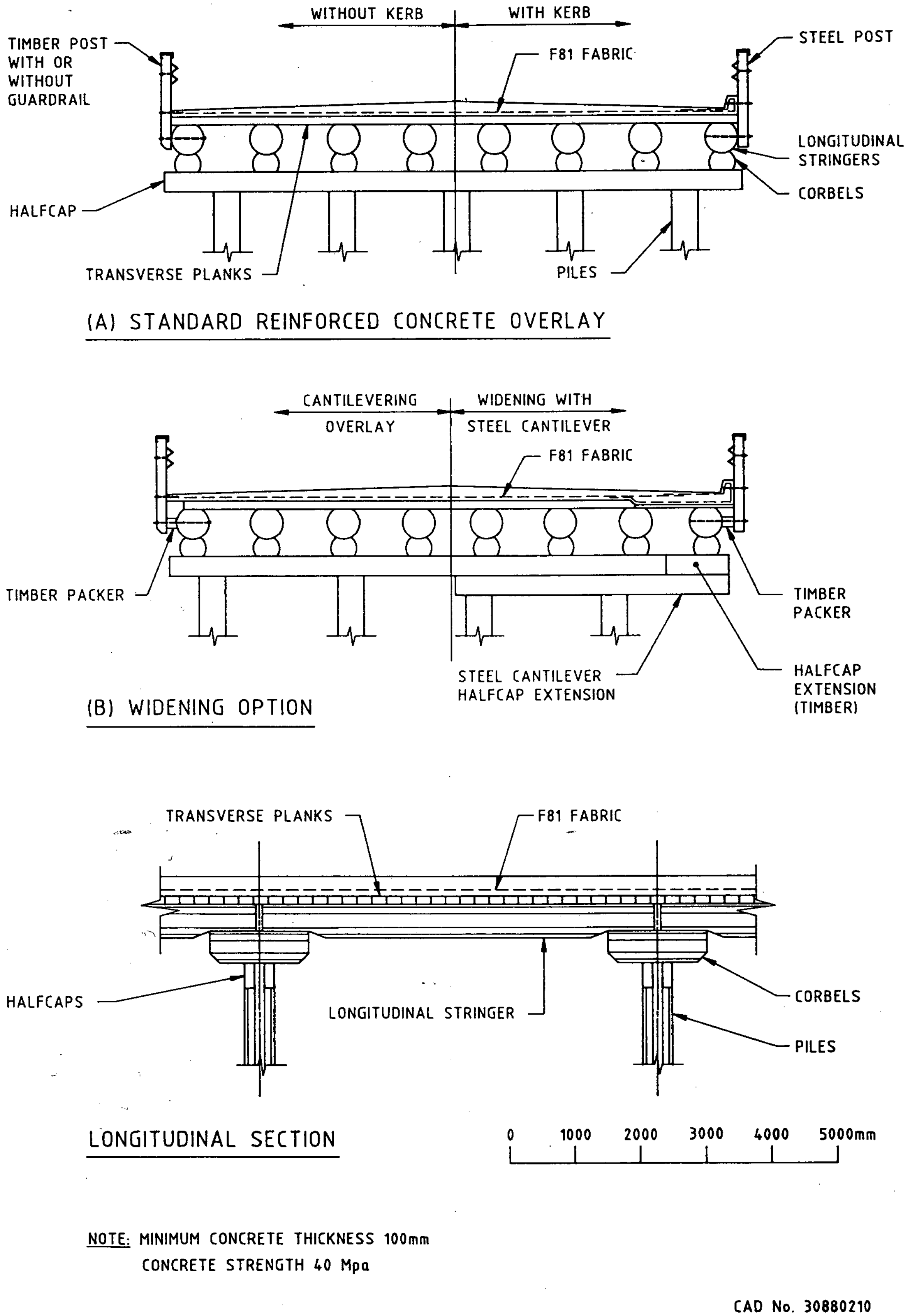


Figure 4 The Reinforced Concrete Overlay and Widening Options

handle and put into the environment the rather toxic chemicals associated with termite control. Severe fungal attack is further controlled by spraying planks with a low toxicity chemical called Boracol, prior to overlaying. More will be said about Boracol in section 4.4 below.

4.2 Enhancements of Superstructures associated with Reinforced Concrete Overlays.

The operational Directorates of the Department managing the various Divisions have a responsibility to develop and maintain a certain standard for Highways and Main Roads, and for allocating funds for similar purposes for Local Authority projects. Where bridges are involved, the structural condition which brings it to attention for an rco provides an opportunity to improve the standard of the structure in other ways. This generally involves a decision about width, standard of guardrail, and in some cases footways. Because virtually all of the timber bridges will be rehabilitated over the next fifteen to twenty years a uniform standard commensurate with National Association of Australian State Road Authorities (NAASRA) standards will be achieved.

Particularly where widening is involved, there are opportunities for engineering design, structural innovations, and to use the results of detailed inspections to make considerable savings and enable the Works Programme to proceed more quickly. From time to time any manager of buildings or structures should do an engineering analysis for the current structural condition, and especially if the loading has changed. The news is not always bad. Re-analysis of a number of old structures has virtually always shown that even partially deteriorated timbers are usually adequate, and that the substructures, particularly on the outer line of piles, are overdesigned despite the fact that NAASRA design highway loadings have increased. This has meant that rco's have been able to be cantilevered out without driving a new line of piles (see Fig.4). The overlay can be cantilevered without support 400 mm on each side, and by supporting with steel channels this can be increased to about 1100 mm without overstressing the piles. In the past most widenings required either one or two lines of piles, usually on one side, which inevitably also required major reconstruction of the abutments. This latter operation can now often be minimised or avoided altogether. There seemed to be an attitude (which also exists outside the Department) that there was little point in redesigning old structures, and so they were simply extended in the same image and likeness as existed previously. However, as has been shown countless times before, engineering design pays.

4.3 Substructure Rehabilitation

As discussed above structural analysis has generally shown the timber piles in the substructure to be overdesigned, so they can suffer significant losses through deterioration without being overstressed. Of course there is a lower limit, particularly when enhancements such as widenings are to be carried out. Once some structural standard has been set for the amount of sound timber needed in a partially rotted or otherwise deteriorated pile, a decision is taken on the basis of what has been found from the detailed inspections as to which of a range of design and management options will be chosen.

In line with the strategy of managing the interaction of water with the structure, rehabilitating and preserving the substructure immediately directs attention to the wetted parts of the timber piles. There are three ways that water can come into contact with piles:

4.3.1 Piles in permanent fresh water.

It has been well established from long experience that timber piles in permanent fresh water last in general at least seventy years without problems, although it is becoming increasingly apparent that banding them as splits appear at around fifty years of age will greatly increase their life.

4.3.2 Water entering at exposed end of pile.

This will cause significant rotting down the centre of the pile by thirty years of age or earlier, even if the pile is otherwise in a safe environment (such as permanent water). Once the heart wood has become rotten it becomes a repository for water with oxygen freely available - ideal conditions for the rot to gradually proceed outward to the more durable timber which forms the basis of the structural strength of the pile.

4.3.3 Pile in damp soil.

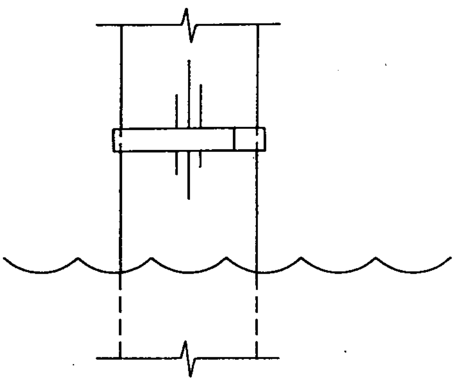
This is the ideal condition for fungal attack, just as a damp gravel pavement rots the deck planks. This is the worst form of attack as the structurally most important outside timber part of the pile is attacked first. Life expectancy of a pile in this stream bank area ranges from less than thirty to approximately fifty years, depending on the conditions of moisture prevailing, and the quality of the original timber. If combined with conditions as in 4.3.2, the pile would fail even sooner.

4.4 Pile Repairs.

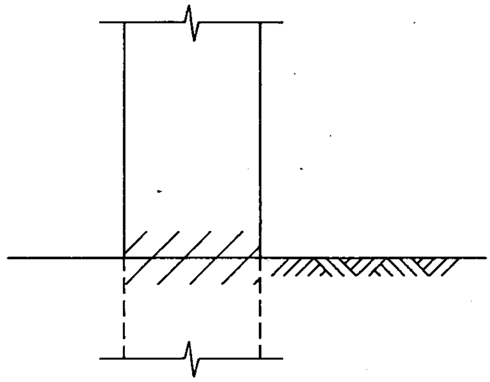
A range of possible pile repairs is shown in Fig. 5. They range from the 'do nothing' option through to a full structural repair or replacement. Aspects of several these alternatives will now be discussed:

4.4.1 Boracol

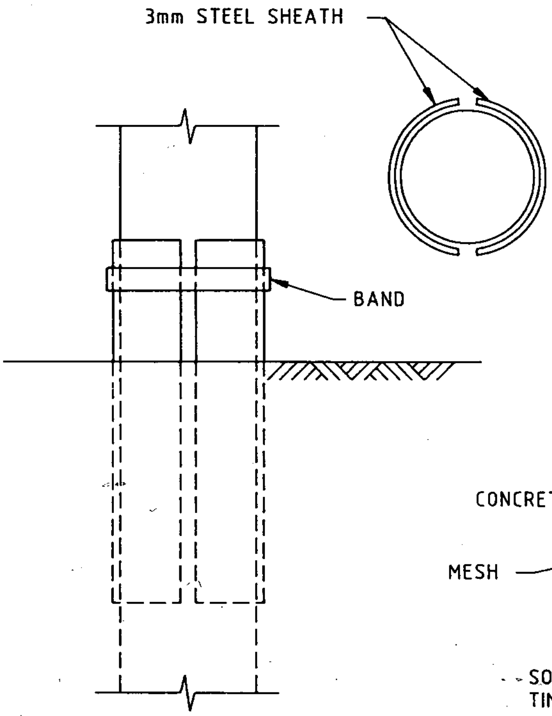
The chemical, Boracol, possibly used in conjunction with Boron Impel Rods is a proprietary system for insitu preservation of timber which was chosen by this Department after exhaustive investigation of alternatives. The key properties it has compared with other systems are as follows:



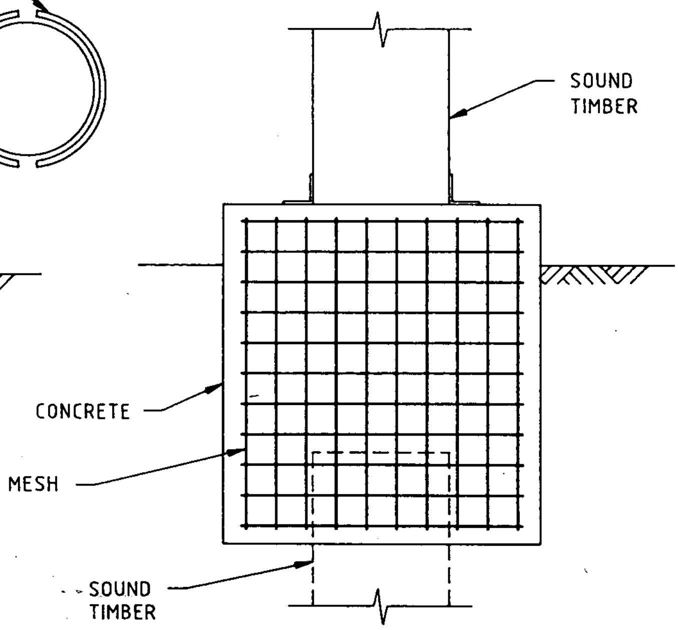
(A) PILE IN SOUND CONDITION - BAND AND WATERPROOF SPLITS AS NECESSARY



(B) COMMENCEMENT OF ROT BUT AT LEAST 100mm OF SOUND TIMBER - TREAT WITH BORACOL, PLUS AS REQUIRED BORON IMPEL RODS



(C) SIGNIFICANT ROT 60 - 100mm SOUND TIMBER. JACK DOWN INTO GROUND 3mm STEEL SHEATH, BAND AT TOP OF SHEATH AND TREAT WITH BORACOL



(D) SEVERE ROT LESS THAN 60mm SOUND TIMBER. EXCAVATE TO SOUND TIMBER, CAST CONCRETE PILE CAP AND MAKE APPROPRIATE STRUCTURAL CONNECTION TO SOUND PILE ABOVE

(E) DRIVE ADJACENT NEW PILE

CAD No. 30880210

Figure 5 Range of Pile Repairs

- it penetrates right through the timber matrix, which is essential for controlling fungal spores which produce rot. The fact that it does permeate the timber also implies that it will eventually leach out, especially if the timber is damp. So there has to be a management programme of monitoring and recharging as necessary.

- although this Department views it as a fungicide, it also creates an environment in which termites cannot survive, because they cannot digest timber treated with Boracol.

- it has very low toxicity, which makes it safe to handle and it is not environmentally damaging.

- it is simple to install, and does not require expensive specialised equipment or skilled operators.

4.4.2 Structural repair of piles using concrete.

As with widening, bridge analysis and design has shown that there are often cheaper alternatives than restoring full axial and bending capacity to the pile. In the past a solution was often adopted where a full structural concrete collar was installed across the rotten region. This is an effective form of treatment, but care must be taken to avoid moisture ingress at the top of the concrete 'pot', or a rot situation will be created. Also the concrete occasionally cracked badly when vibrated by the traffic during setting.

The most recent solution is as shown in Fig. 5. Most timber piles are about eight to eleven metres long, and only 500 mm of this length at and below the ground line is affected by rot. Below this level there is insufficient oxygen for the fungal spore to exist. So the preferred solution now is to prop around the damaged pile, excavate to the level of sound timber, and remove all the rotted timber. A concrete 'pile cap' is then cast over the sound timber under the ground which, being in the anaerobic zone should now last indefinitely. Depending on what is structurally required, a full moment connection can now be made from the upper segment of pile to the pile cap, or more commonly and much more cheaply, a simple bearing connection to the cap. As the cap concrete has set before being connected to the rest of the bridge, it is not cracked by traffic vibration. The connection detail to the upper part of the pile is made above ground where it can easily be inspected and maintained.

4.4.3 Steel splint repairs

It is intended to try using a steel splint repair as shown in Fig. 5, which should be cheaper than the full structural repair, and adequate for some intermediate cases, especially used in conjunction with Boracol. To date this solution has not been tried.

4.5 Abutment Repairs

The other part of the bridge which is in intimate contact with damp earth is the abutment. Most of these are timber sheeted or in some cases bedlog. If the earth behind the abutment is damp, the sheeting is not likely to last more than about thirty years, especially as sawn timber lasts considerably less well than round timber. If the abutment piles have also failed, the entire abutment is replaced with concrete, which is a structurally connected to the sound portion of the pile under the ground, and the concrete overlay on top. The old rotten sheeting becomes the back formwork for the new concrete. If the piles are adequate they can simply be treated with Boracol, and the sheeting replaced by either concrete or new timber sheeting in front of the old. Unfortunately it is impossible to treat the sheeting with Boracol because the fungal attack comes from the earth behind the abutment, but replacement timber with good drainage behind such as 'core drain' should last much better than the old sheeting in direct contact with the damp earth. Considerable savings have been achieved when abutment treatments as described have been carried out, and the traditional necessity to excavate and reinstate all the earth behind the abutment is also avoided. The latter not only saves money but also avoids an operation which can be very disruptive to traffic.

4.6 Philosophy of Maintenance Design

It has been emphasised that managing the interaction of water with the structure is the key to producing longevity at minimal cost. A spectrum of design alternatives has been given, which shows how the environment in which the bridge has to exist has to be controlled to either exclude water or to overcome its effects. Of course there are times when a bridge's state of deterioration combined with structural alterations for widening or strengthening will result in replacement being the most economic alternative. The philosophy is still the same. The abutments are well drained. A concrete deck with flashing in appropriate places will protect the timber superstructure and upper part of the substructure from moisture. All open ends of piles will be protected from ingress of water, and after an appropriate period the piles in the wet zone will become treated on a regular basis with Boracol.

It should be obvious by this time that the whole management philosophy hinges on a continuing programme of well documented systematic inspections. The design solutions chosen simply could not be contemplated without an ongoing committment to inspection. But the resultant direct savings are enormous, and the capacity to provide an uninterrupted service while minimising cash flows and costs to the community more than justifies the expenditure on these inspections. Wherever significant structural work is to be carried out on a bridge a detailed inspection will have to be made before the commencement of operations anyway, and it is much better to have done this well in advance.

5. RESEARCH AND DEVELOPMENT PROGRAMME

With any broad engineering problem such as this, it will be necessary to have a formal Research and Development programme. This is particularly true for the timber management area because there has been comparatively little published on it in the past, as the replacement option was so widely used. Staff involved are encouraged to read the literature, attend technical seminars, to prepare and present papers, and to institute and play an active role in research programmes. Several items currently under investigation include:

- dispersion rates of Boracol in aged hardwoods.
- rate at which rot proceeds under various conditions.
- temperature movements in rco's.
- non-destructive assessment of timber condition.

6. CONCLUSIONS

This paper has given a wideranging picture of many aspects of managing a large group of aging timber bridges. However a number of conclusions can now be drawn:

- once there is a large enough number of bridges involved, the expert knowledge required, the efficient use of facilities, and the effect on the organisation budget suggests that central management is required. The infrastructure to carry out this task has been installed at the Main Roads Department of Western Australia and it now manages all road bridges (timber and non timber) in Western Australia. There is another large group of aging bridges in Western Australia, the railway bridges. It may be of considerable economic benefit to include them in the same central management system.
- efficient central management is built around a systematic structural inspection programme and a computer based information system. These are used to develop a programme of actions and the computer system allows approriate interaction between all relevant personnel, and also effectively disseminates current information.
- once this information infrastructure is in place, the certainty of regular inspections allows a much larger range of design options to be considered which leads to enormous savings.
- engineering reappraisal of old structures can lead to considerable savings when they have to be modified or rehabilitated.
- ongoing research and development is also an integral part of ensuring that the best solutions are being obtained and correctly implemented.

ACKNOWLEDGEMENT

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